

Aerobraking

Once a spacecraft achieves orbit, atmospheric drag at periapsis can be used to modify the orbit. This fuel-saving technique is referred to as aerobraking.

JPL

Mars Global Surveyor Project MGS Aerobrake Baseline Profile



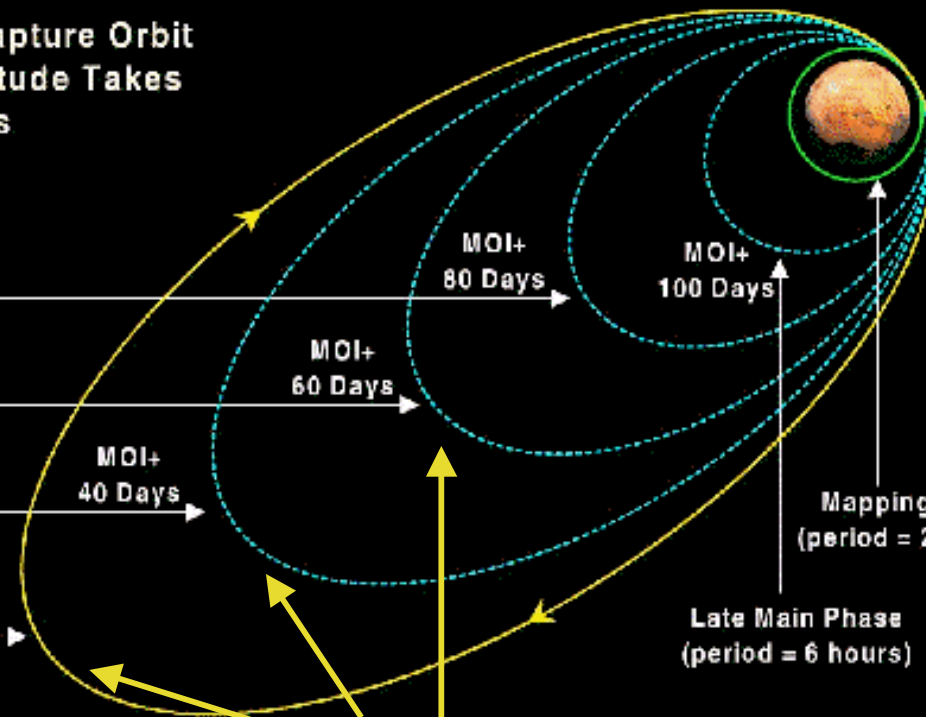
Aerobraking From Capture Orbit
to Mapping Orbit Altitude Takes
About 130 Earth Days

Middle Main Phase
(period = 12 hours)

Early Main Phase
(period = 24 hours)

Early Main Phase
(period = 34 hours)

Initial Capture Orbit
Walk-In Phase
(period = 48 hours)



← K.E. lost here

□V's here to raise/lower periapsis, and control the rate of aerobraking

WJ JLC
May 1995

The Aerobraking Process

- *Once a spacecraft is in its initial orbit, a series of ΔV 's are employed at apoapsis to lower the orbit periapsis to the altitude at which aerobraking will occur. (Spacecraft heating is an issue if periapsis is too low.) 'walk-in phase'*
- *The spacecraft then remains in this orbit until the apoapsis altitude approaches the desired orbital altitude. (This phase of the aerobraking process can take months, depending on how deep the spacecraft is allowed to dip into the atmosphere.) 'main phase'*
- *At this point, ΔV 's can then be applied to raise periapsis to the desired final altitude, while perhaps lowering apoapsis. (Usually the final orbit to be achieved is circular.) 'walk-out phase'*

Advantages/Disadvantages

- *Aerobraking conserves fuel, mass, volume, and cost, for both spacecraft and launch vehicle.*
- *Knowledge of the density and variability of the planet's upper atmosphere is poorly known, increasing mission risk.*
- *Aerobraking is a lengthy process, which can often last over several months.*

Aerobraking Experiment at Venus

Magellan was the first orbiting planetary spacecraft to use atmospheric drag, or aerobraking, to change its orbit.

Launched: May 4, 1989 Arrived at Venus: August 10, 1990

Initial orbit: Highly elliptical polar, 3-hr 15 min. orbit

--> periapsis 294 km; --> apoapsis 8543 km

Over the next 3 years, Magellan used radar to penetrate the dense cloud cover surrounding Venus and map its surface.

An aerobraking experiment was then performed:

May 25, 1993: periapsis lowered to 140 km

August 3, 1993: aerobraking completed

Final orbit: 180 x 541 km; 94 min.

Atmospheric entry: 11 Oct 1994 - 14 Oct 1994

(aerodynamic heating of the spacecraft was much less than expected)

September, 1994: *'windmill experiment'*

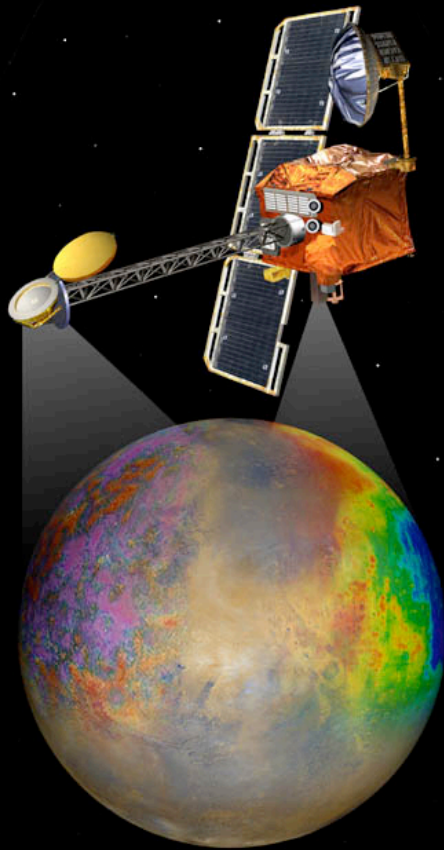
the spacecraft's solar panels were turned to a configuration resembling the blades of a windmill, and Magellan's orbit was lowered. Flight controllers then measured the amount of torque control required to maintain Magellan's orientation and keep it from spinning, new information useful in designing future spacecraft.



Composite SAR image of Venus from Magellan data

Aerobraking at Mars: Odyssey

The Odyssey spacecraft, which was launched in 2001, also successfully utilized aerobraking during its mission.



**Artist's Conception:
Odyssey Spacecraft
during Aerobraking**



- *Odyssey skimmed through the upper reaches of the Martian atmosphere 332 times.*
- *By using the atmosphere of Mars to slow down the spacecraft in its orbit rather than firing its thrusters, Odyssey was able to save more than 200 kilograms of propellant.*
- *This reduction in spacecraft weight enabled the mission to be launched on a Delta II 7925 launch vehicle, rather than a larger, more expensive launcher.*

The Challenges of Getting to Mars:

AEROBRAKING

MGS Aerobraking: The Original Mission Plan

Following orbit insertion, MGS began aerobraking

Initial orbit: highly eccentric; 263 x 54,026 km ; T=45 hours; i = 93.26 deg

Desired orbit: near-polar near-circular sun-synchronous (near-uniform coverage over most of the planet)

Planned Aerobraking

- *Walk-in phase: The orbit periapsis is lowered from the capture orbit altitude of 263 km to the altitude at which aerobraking will occur through a series of small propulsive maneuvers.*
- *The spacecraft will remain at the aerobraking altitude during the main phase for three months as the apoapsis altitude is slowly lowered from 54,000 km to about 2000 km and the orbital period is reduced to under 3 hours.*
- *The final three weeks of aerobraking constitute walk-out which reduces the apoapsis altitude to 450 km while slowly increasing the periapsis altitude.*

Planned Aerobraking (cont.)

- *The descending orbit node location will have rotated from its initial position near 5:45 PM to nearly 2:00 PM. At this point aerobraking is terminated with a maneuver which raises periapsis out of the region of significant drag.*
- *Following the completion of aerobraking, final mapping orbit adjustments are made and the spacecraft and instruments are prepared for the start of mapping which will begin in March 1998. Mapping will continue for a full Mars year (687 days).*

Risk Aspects of MGS Aerobraking:

In contrast to Magellan at Venus, aerobraking precedes the main mapping activity; therefore mission success depends on successful aerobraking

Science constraints require 2:00 pm sun-synchronous orbit. Aerobraking must proceed on a schedule such that this constraint is met at the end of aerobraking.

Actual Aerobraking

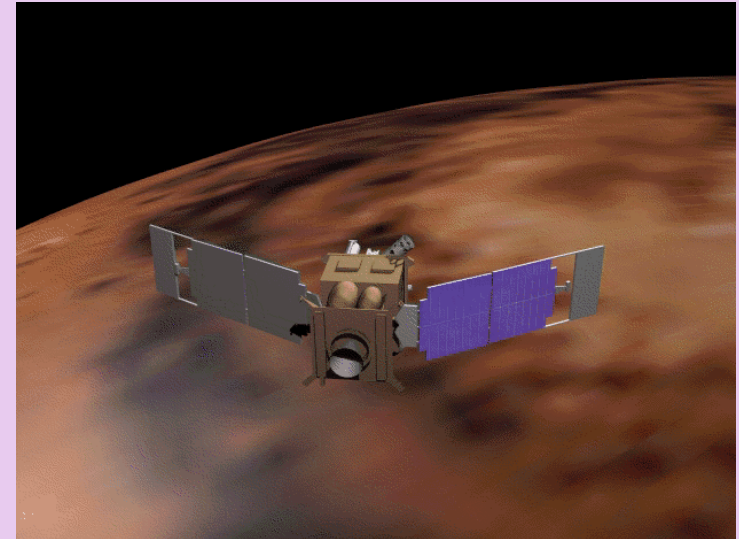
- Aerobraking was initialized by gently stepping into the atmosphere by lowering the periapsis altitude through a series of small propulsive maneuvers executed at apoapsis.*

<u>Walk-in Phase</u>			
Maneuver	ΔV (m s⁻¹)	Periapsis (km)	ρ & ρV^2 (kg km⁻³; N m⁻²)
-----	-----	-----	-----
3 AB-1	4.4	149.3	0.36; 0.00 at P4
4 AB-2	0.8	128.4	5.61; 0.06 at P5
5 AB-3	0.3	121.4	10.7; 0.12 at P6
7 AB-4	0.2	116.1	20.1; 0.23 at P8
10 AB-5	0.2	111.2	42.2; 0.49 at P11
11 AB-6	0.05	110.5	45.7; 0.53 at P12

Note: The first periapsis that occurred during the MOI maneuver is designated as P1

Simulation of the reconfiguration of the solar arrays on the Mars Global Surveyor spacecraft for Aerobraking. The reversal of the minus y-axis solar panel is a result of that panel not latching after initial deployment just after launch

MGS Aerobraking configuration



The aerobraking process begins with the spacecraft configuring itself in an orientation to increase drag. Both Magellan and Mars Global Surveyor used their flat solar panels and high gain antenna dishes to provide a large profile area. MGS also released extra flaps located at the end of the solar panels to further increase the drag.

MGS Aerobraking: Main Phase Aerobraking and Temporary Suspension

- *The next phase, called the main phase, was defined by a dynamic pressure corridor with upper and lower limits being 0.68 Nm^{-2} and 0.58 Nm^{-2} respectively.*
- *The upper limit provided for adequate orbit period reduction and safety against aerodynamic heating of critical spacecraft components.*
- *The lower limit insured a minimum level of orbit period reduction.*
- *Shortly after beginning the main phase, a problem with the minus-Y axis solar array developed which necessitated a temporary suspension of aerobraking.*
- *Periapsis was raised to 172 km to look at the problem.*

MGS Aerobraking:

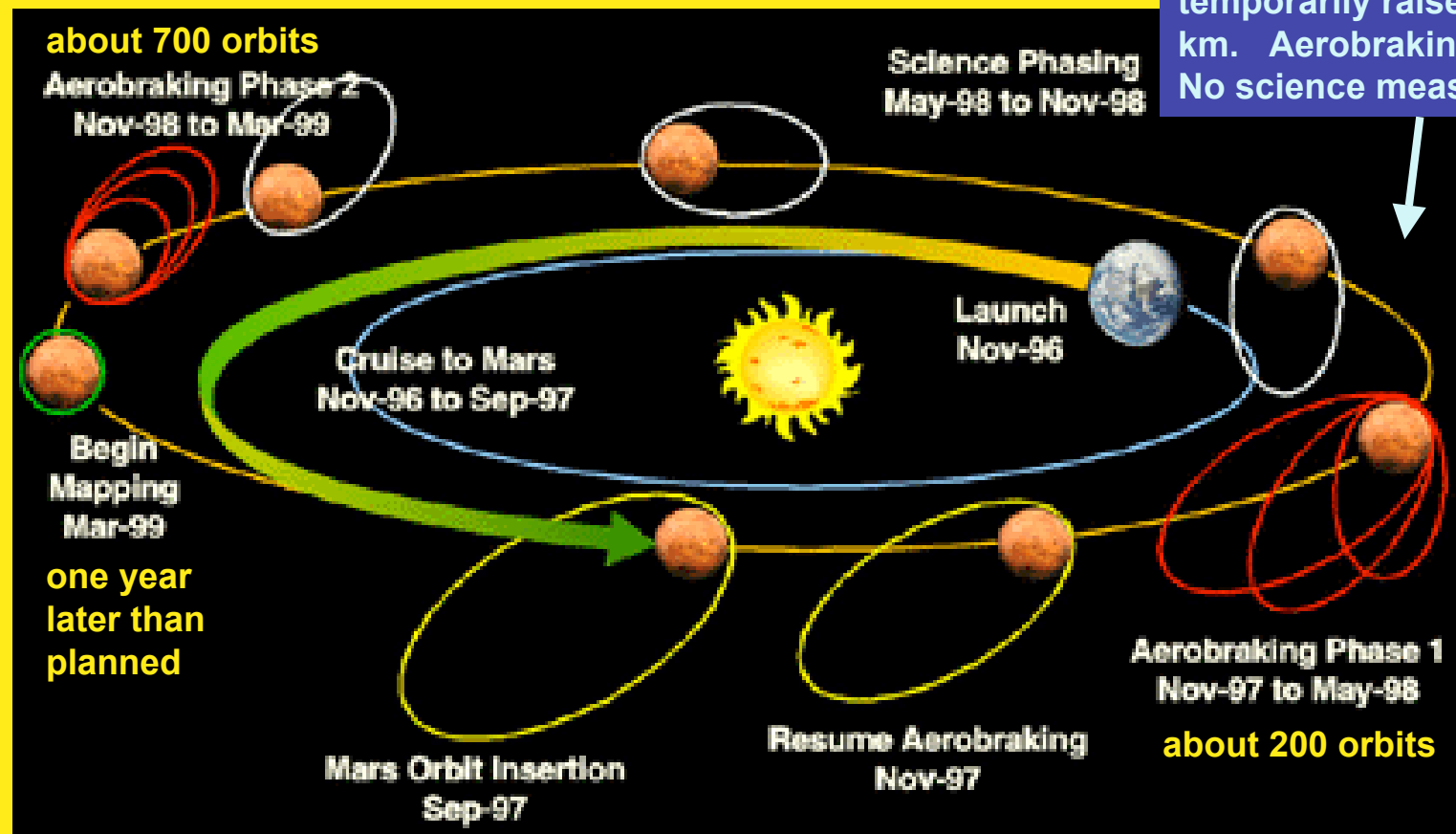
Main Phase Aerobraking and Temporary Suspension

- If further aerobraking was not possible, this could severely impact the mission. For instance, the Mars Orbiter Laser Altimeter (MOLA) could only acquire a return signal when the range to the surface was less than about 780 km.*
- In addition, because aerobraking had been halted, it was no longer possible to reach the 2:00 PM equator crossing orbit for which the mission was designed. This orbit was also necessary to optimize power and communications with earth.*
- After an engineering evaluation, it was concluded that one of the face sheets of the yoke attaching the solar array to the gimbel motor had sustained a crack. The revised plan called for a reduced level of aerobraking, thus subjecting the solar array to less aerodynamic stress.*
- The new dynamic pressure corridor was set to 0.15 to 0.25 Nm⁻².*

MGS Aerobraking: Phases I and II

The second phase of aerobraking did not need to start until fall, 1998, so the intervening six months were used for science observations ('Science Phasing Orbit') with the spacecraft pointing the instruments toward the planet at each periapsis.

Solar conjunction, May of 1998. Communications unreliable. Periapsis temporarily raised to 170 km. Aerobraking halted. No science measurements.

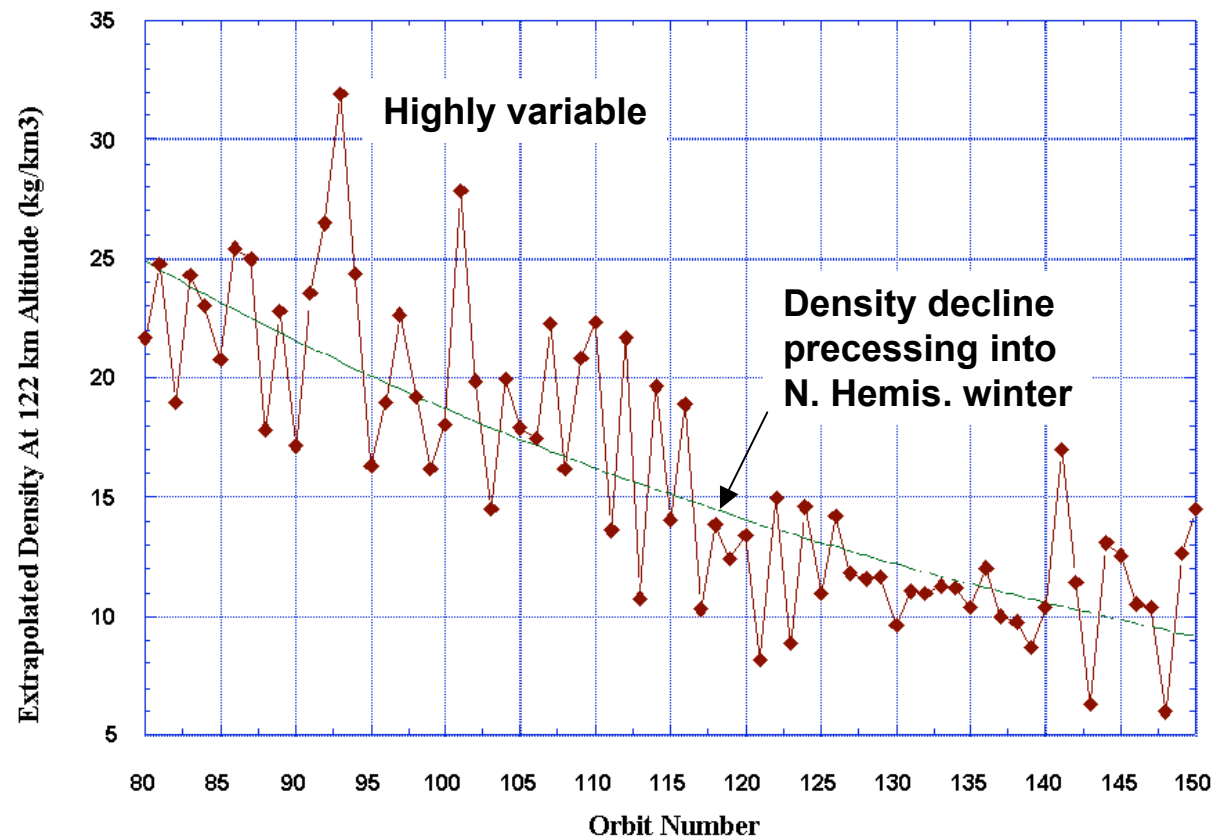


Note: The original aerobraking plan was for 300 orbits; instead it took ~900 orbits and 1 additional year.

MGS Aerobraking: Variability of Density at Periapsis

Variations in atmospheric density can be appreciable, requiring orbit by orbit evaluations by the flight team to determine whether or not the periapsis altitude should be lowered to maintain a steady decrease in orbit period, or increased to avoid large forces on the solar arrays.

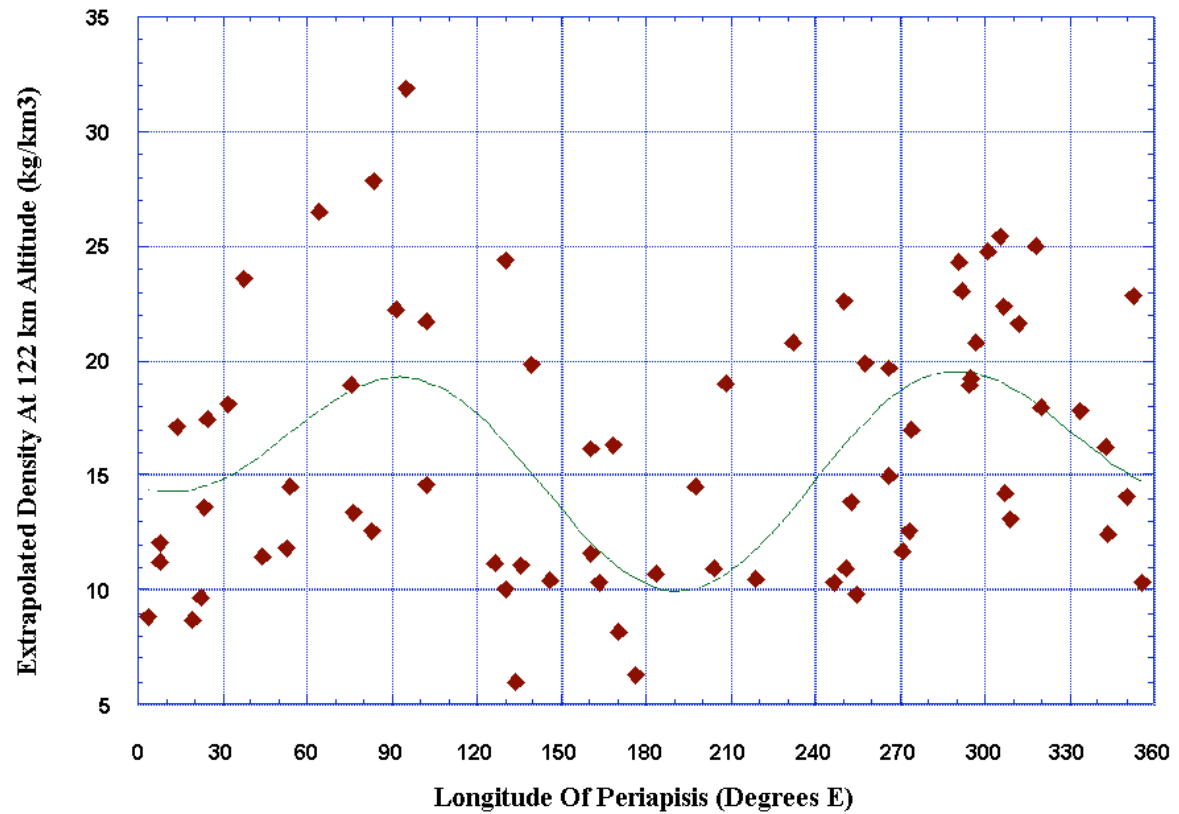
The Density Measured at Each Periapsis is Extrapolated to a Constant Altitude of 122 km and Plotted in this Figure For Orbits 80-150 (2 January 1998-27 February 1998). The Smooth Green Curve is a Least Squares Exponential Fit to the Points Shown, Illustrating the Slow Decline in Atmospheric Density Experienced as the Spacecraft Periapsis Moved North into N. Hemisphere Winter.



MGS Aerobraking: Variability of Density at Periapsis

One of the unanticipated results from aerobraking in the Northern hemisphere of Mars is the discovery that there is a longitude dependence to the density variations which is related to surface topography.

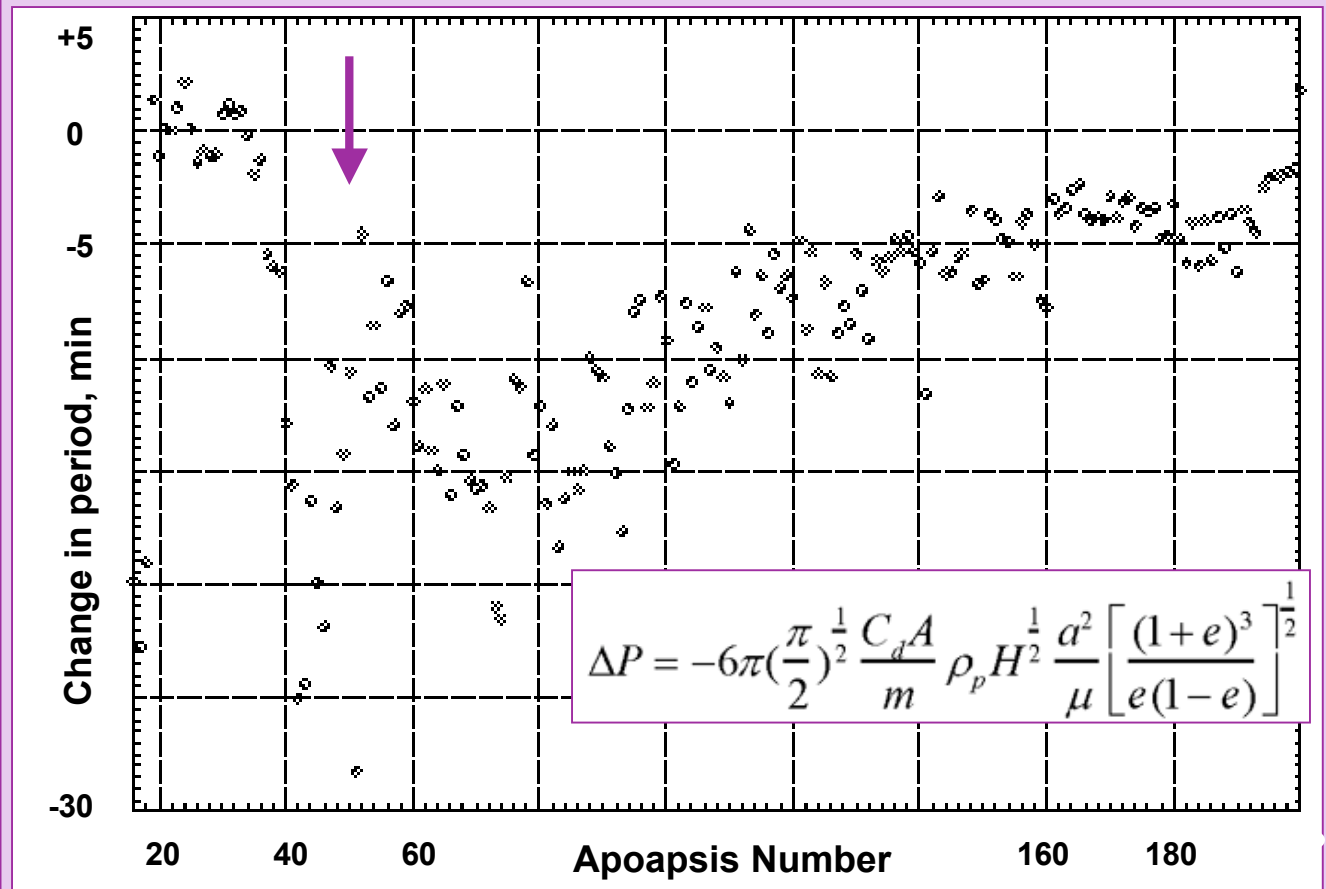
The Extrapolated Periapsis Density at an Altitude Of 122 km as a Function of the Periapsis Longitude for Orbits 80-150. The Smooth Green Curve is a Least Squares Fit to the Data Using a Constant Term, Two Sine Terms, one Wave-1 and one Wave-2.



MGS Aerobraking: Variability of Orbital Period

Between orbits 40 and 60, a dust storm occurred that inflated the atmosphere and caused the density at periapsis to increase by 133%. The periapsis was raised until the storm effects subsided. It did not turn out to be as large a storm as some in the past.

The design had a margin of 90% with respect to unpredictable changes in atmospheric mass density at periapsis. This means that the spacecraft could tolerate at least an unpredicted change of 90% in the periapsis density without exceeding a heating constraint of 0.68 Wcm^{-2} (given the 17 m^2 projected area of the spacecraft this corresponds to a maximum dissipation of 116 kilowatts near periapsis).



Period Changes Per Orbit During Phase I Aerobraking